Free Executive Summary

Strategies to Protect the Health of Deployed U.S. Forces: Force Protection and Decontamination

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Executive Summary

Since Operation Desert Shield/Desert Storm, Gulf War veterans have expressed concerns that medical symptoms they have experienced could have been caused by exposures to hazardous materials or other deployment-related factors associated with their service during the war. Potential exposure to a broad range of chemical and/or biological (CB) and other harmful agents was not unique to Gulf operations but have been a component of all military operations in this century. Nevertheless, the Gulf War deployment focused national attention on the potential, but uncertain, relationship between the presence of CB agents in theater and health symptoms reported by military personnel. Particular attention has been given to the potential long-term health effects of low-level exposures to CB agents.

Since the Gulf War, U.S. forces have been deployed to Haiti, Somalia, Bosnia, Southwest Asia, and, most recently, Kosovo, where they were (and are) at risk of exposure to toxic CB threats. The U.S. Department of Defense (DoD) anticipates that deployments will continue in the foreseeable future, ranging from peacekeeping missions to full-scale conflicts. Therefore, the health and preparedness of U.S. military forces, including their ability to detect and protect themselves against CB attack, are central elements of overall U.S. military strength. Current doctrine requires that the military be prepared to engage in two simultaneous major regional conflicts while conducting peacekeeping operations and other assignments around the globe. The diversity of potential missions, as well as of potential threats, has contributed to the complexity of developing an effective strategy.

BACKGROUND

In the spring of 1996, Deputy Secretary of Defense John White met with the leadership of the National Academies to discuss the DoD's continuing efforts to improve protection of military personnel from adverse health effects during deployments in hostile environments. Although many lessons learned from previous assessments of Operation Desert Shield/Desert Storm have been reported, prospective analyses are still needed: (1) to identify gaps and shortcomings in policy, doctrine, training, and equipment; and (2) to improve the management of battlefield health risks in future deployments.

DoD determined that independent, external, unbiased evaluations focused on four areas would be most useful: (1) health risks during deployments in hostile environments; (2) technologies and methods for detecting and tracking exposures to harmful agents; (3) physical protection and decontamination; and (4) medical protection, health consequences and treatment, and medical record keeping. This report, which addresses the issues of physical protection and decontamination, is one of four initial reports that will be submitted in response to that request.

CHARGE

This study, conducted by two principal investigators with the support of an advisory panel and National Academies staff from the Commission on Engineering and Technical Systems, assessed DoD approaches and technologies that are, or may be, used for physical protection—both individual and collective—against CB agents and for decontamination. This assessment includes an evaluation of the efficacy and implementation of current policies, doctrine, and training as they relate to protection against and decontamination of CB agents during troop deployments and recommends modifications in strategies to improve protection against deleterious health effects in future deployments. This report includes reviews and evaluations of the following topics:

- current protective equipment and protective measures, as well as those in development
- current and proposed methods for decontaminating personnel and equipment after exposure to CB agents
- current policies, doctrine, and training for protecting against and decontaminating personnel and equipment in future deployments
- the effects of using current protective equipment and procedures on unit effectiveness and other human performance factors
- current and projected military capabilities to provide emergency response to terrorist CB incidents

THREAT AND RISK ASSESSMENT

Chemical and Biological Battle Space

Chemical agents were first used extensively as military weapons during World War I. CB weapons programs continued to flourish during the 1950s and 1960s, led by scientists in the United States and the Soviet Union, and to a lesser extent, in other countries including Great Britain. New nerve agents were developed during those years, including the family of V agents, which are not only lethal in smaller ingested doses but can also be absorbed directly through the skin. Natural toxins and biological pathogens were also investigated as biological warfare agents.

In the post-1950s era, improving the means of dissemination of lethal agents became a major research objective. Airborne spray tanks, specialized artillery shells, CB-capable missile warheads, and an assortment of other weapons were developed. The United States discontinued its offensive biological and chemical military research programs in 1969 and 1989, respectively, but continued to expand its defensive programs. However, CB technologies have continued to proliferate in other countries, and with advances in bioengineering and molecular biological capabilities, even small nations or groups now have the potential to develop novel biological agents. This asymmetrical threat prompted the United States to extend its CB defense programs, which have increased substantially since Desert Shield/Desert Storm.

The estimated CB threat from Soviet forces during the Cold War was based on the perceptions that a broad range of chemical and biological weapons had been fielded, that the Soviet Union had the capability of deploying and supporting those weapons on the battlefield, and that the Soviets were pursuing an extensive research program. U.S. tactics, training, and requirements were based on this perceived threat. Today, many countries possess CB capabilities although intelligence assessments indicate that most of them have limited quantities of agents and limited delivery systems.

Response to Chemical/Biological Threats

The CB threat to U.S. forces can be defined as the perceived capability of an opposing force to expose U.S. forces to CB agents. The most obvious way to minimize the risk of CB exposure is to avoid contact with these materials. Therefore, the military has developed a doctrinal principle for protecting deployed forces based on avoiding exposure (i.e., contamination avoidance). Avoiding contact depends on the capability and availability of detection equipment; however, because of current lag times in

detection capability, a responsive strategy (the so-called "detect to treat" strategy), rather than a preventive strategy, has been necessary.

The U.S. intelligence community provides data, analyses, and advice concerning the development of CB capabilities by threat nations. Based on this information, commanders and the Joint Service Integration Group (JSIG) evaluate how CB agents could be used against U.S. troops and develop policy, doctrine, training, and requirements for equipment to counter the perceived threat. As the threat changes, U.S. approaches to countering the threat should also change.

As a result of the proliferation of CB capabilities, recent reductions in U.S. forces, continuing budget constraints, and attempts to minimize duplications of effort among the services, operations have become more integrated and cooperative (i.e., joint service operations). To encourage the integration of CB research and development (R&D) at all levels, in 1994 Congress enacted Public Law 103-160, the National Defense Authorization Act for Fiscal Year 1994 (Title XVII), establishing a new structure for the CB defense program.

Finding. Joint structure and joint service processes were developed to maximize the efficient use of funds and reduce duplications of effort.

Finding. The object of the joint prioritization of system needs (and, therefore, research, development, and acquisition [RDA] needs) is to ensure that fielded systems meet joint service needs. This requires that commander-in-chief (CINC) priorities and nuclear, biological, chemical (NBC) community priorities be coordinated.

Finding. The prioritization and selection of RDA projects are often based on compromises or political trade-offs unrelated to CINC prioritization, technical capabilities, or bona fide needs and are focused on service-specific rather than joint service needs.

Recommendation. The Department of Defense should reevaluate and possibly revise its prioritization process for the development of equipment. The reevaluation should include reassessment of the use of threat information.

Challenge

The chemical agent challenge established for protective equipment ($10 g/m^2$ for liquids; 5,000–10,000 mg-min/m^3 for vapors) has not been changed in four decades. Although analyses using relatively sophisticated computer models have shown that under certain conditions,

10 g/m^2 levels may be present in localized areas of a battlefield, the average concentration may be considerably lower. These same models predict that the areas where levels would be higher than 10 g/m^2 would be the same areas where the shrapnel and projected shell materials would be more likely to cause injuries or deaths than CB agents. Nevertheless, because challenge levels determine the requirements for protection, the goals of the entire CB R&D program are based on the 10 g/m^2 level for liquid agents and 5,000–10,000 mg-min/m^3 for vaporous agents.

Finding. The battlefield areas with the highest contamination levels will also have the highest levels of ballistic fragmentation lethalities. Therefore, CB protective measures will be ineffective in these areas regardless of the liquid or vapor challenge levels. The threat from CB weapons relative to other battlefield threats is unknown.

Finding. System development is sometimes based on outdated and possibly inaccurate evaluations of threats and challenges.

Recommendation. The Department of Defense should reevaluate the liquid and vapor challenge levels based on the most current threat information and use the results in the materiel requirements process and, subsequently, in the development of training programs and doctrine.

Finding. Little or no new funding is being provided for basic research on new technologies for physical protection or decontamination.

Recommendation. The Department of Defense should reprogram funds to alleviate the shortfall in basic research on new technologies for physical protection and decontamination.

PHILOSOPHY, DOCTRINE, AND TRAINING

The CB defense program involves (1) contamination avoidance (reconnaissance, detection, and warning); (2) force protection (individual and collective protection and medical support); and (3) decontamination. Before systems for detecting contaminated areas were available, military planners developed a doctrine (best described as the "fight dirty" doctrine) that was based on conducting operations in contaminated areas. Implementing the doctrine involved providing a combination of individual protective equipment and extensive training on fighting in contaminated environments. As technology has advanced, especially detection technologies, and as new detection equipment has been fielded, the doctrine has shifted to "contamination avoidance." Stated simply, this

doctrine provides that U.S. forces will engage an enemy while avoiding casualties from contamination by CB agents.

Once the doctrine of contamination avoidance (with concomitant detection and protective equipment) was adopted, training was naturally modified to carry out the new doctrine. A critical requirement for deterring the use of CB agents (and for successful operations if deterrence fails) is that forces be fully trained to respond to the full spectrum of CB threats. Operational requirements must balance the risk factors from all sources and determine trade-offs between protecting the individual and maintaining the combat effectiveness of the force.

Finding. The current doctrine is based on the concept of contamination avoidance, although U.S. CB detection systems do not, as a rule, provide sufficient advance warning to prevent exposures.

Finding. Unit commanders receive little training related to assessing CB risks to their units, especially in determining when, whether, and how much protective gear is necessary.

Recommendation. The Department of Defense should develop commander training protocols and/or simulations to assist unit leaders in making appropriate chemical and biological risk-based decisions.

INDIVIDUAL PROTECTION

The military conceptual approach to individual protection, called mission-oriented protective posture (MOPP), is an ensemble comprised of protective garments, boots, masks, and gloves. MOPP levels proceed (i.e., adding parts of the ensemble) from the MOPP-ready level to the MOPP 4 level, increasing the level of protection in response to the hazard. Because design requirements for personal protective equipment (PPE) include the ability to withstand the established threat and risk levels, PPE has severely limited individual (and unit) performance. Problems include difficulties in speech and communications, impairment in hearing, reduced vision, thermal stress, occasional adverse reactions to materials, and overall reductions in operational effectiveness.

Some improvements in PPE have been made, however. For example, the joint service lightweight integrated suit technology (JSLIST) affords better CB protection, reduces the physiological heat burden, and interferes less with weapons systems than previous technologies. The JSLIST preplanned product improvement (P3I) should provide even better protection. Because the human respiratory system is extremely vulnerable to

the highly toxic and rapidly acting agents to which deployed forces may be exposed, respiratory protection is a major factor in contamination avoidance. Respirators of various types have been developed and used both in military and civilian operations. The newest mask—the joint service general purpose mask (JSGPM)—allows better peripheral vision, is reasonably comfortable to wear, and has a somewhat flexible design to meet service-specific requirements.

The hands have traditionally been protected by impermeable gloves; however, recent research has also focused on multilaminate technologies and barrier creams designed to prevent or reduce the penetration and absorption of hazardous materials by the skin, thus preventing skin lesions and/or other toxic effects. Effective barrier creams might also be used to protect skin adjacent to areas where the garments are known to provide less than optimal protection (e.g., under seams, around closures).

Finding. Current challenges used to evaluate protective equipment do not reflect changes in threat levels.

Recommendation. The Department of Defense should reevaluate its requirements for materiel development to protect against liquid and vapor threats and revise design requirements, if appropriate.

Finding. PPE modules (e.g., masks, garments, gloves) were designed as independent items and then "retrofitted" to create an ensemble. They were also developed without adequate attention to various human factors issues, such as the integration of PPE with weapon systems.

Finding. The most serious risk from most CB agents appears to be from inhalation. Current doctrine allows for Mask-Only protection, but the mask seal could be broken while advancing from Mask-Only to MOPP 4 status.

Recommendation. A total systems analysis, including human factors engineering evaluations, should be part of the development process of the personal protective equipment system to ensure that the equipment can be used with weapon systems and other military equipment. These evaluations should include:

- the performance of individuals and units on different tasks in various realistic scenarios
- the interface of the mask and garments and potential leakage during an "advance" from Mask-Only to MOPP 4 status

Finding. Although researchers have good data from human factors testing that identified serious performance (cognitive and physical) limitations as a result of wearing PPE, they have been unable to adequately relate these deficiencies to performance on the battlefield.

Recommendation. The Department of Defense should place greater emphasis on testing in macroenvironments and controlled field tests rather than relying mostly on systems evaluations for personal protective equipment.

Finding. Although the seal of the mask is much improved over previous mask models, seal leakage continues to be a critical problem. The leakage can be attributed to (1) problems with the interface between the seal and the face, and (2) improper fit.

Recommendation. Additional research is needed on mask seals and mask fit. The research program should focus on seals, fit, and sealants (adhesives). The duration/severity of leaks, if any, during transitions in protective posture from one MOPP level to another should also be investigated. These data would be useful for future studies on long-term health effects of low-level exposures. In addition, training to fit masks properly should be conducted for all deployed forces equipped with mission-oriented protective posture equipment.

Finding. Although mask fit testing has been shown to improve protection factors 100-fold, the Air Force and Army have only recently begun deploying mask fit testing equipment and providing appropriate training protocols and supportive doctrine.

Recommendation. Doctrine, training, and equipment for mask fit testing should be incorporated into current joint service operations. The Department of Defense should deploy the M41 Mask Fit Test kit more widely.

Finding. Leakage around closures in personal protective equipment remains a problem.

Recommendation. The Department of Defense should continue to invest in research on new technologies to eliminate problems associated with leakage around closures. This research could include the development of a one-piece garment, the use of barrier creams on skin adjacent to closure areas, and other technologies still in the early stages of development.

Finding. Current gloves reduce tactile sensitivity and impair dexterity.

Recommendation. The Department of Defense should evaluate using a combination of barrier creams and lightweight gloves for protection in a chemical and/or biological environment. Multilaminate gloves should also be further explored.

Finding. An impermeable garment system is believed to provide the most comprehensive protection against CB agents. But impermeable barriers cause serious heat stress because they trap bodily moisture vapor inside the system. Permeable systems, which breathe and allow moisture vapor to escape, cannot fully protect against aerosol and liquid agents.

An incremental improvement could be achieved by using a semipermeable barrier backed with a sorptive layer. This system would allow the moisture vapor from the body to escape and air to penetrate to aid in cooling. The multilayer system would have some disadvantages, however. It would be bulky and heavy. The sorptive layer is an interstitial space where biological agents could continue to grow because human sweat provides nutrients for biological agents, which could prolong the period of active hazards. Countermeasures should be investigated to mitigate these problems.

Recommendation. The Department of Defense should investigate a selectively permeable barrier system that would be multifunctional, consisting of new carbon-free barrier materials, a reactive system, and residual-protection indicators.

The carbon-free barrier materials could consist of: (1) smart gel coatings that would allow moisture/vapor transport and would swell up and close the interstices when in contact with liquid; (2) selectively permeable membranes that would allow moisture/vapor transport even in the presence of agents; (3) electrically polarizable materials whose permeability and repellence could be electronically controlled.

The reactive material could be smart, carbon-free clothing with gated membranes capable of self-decontamination. A reactive coating could also be applied to the skin in the form of a detoxifying agent (e.g., agent reactive dendrimers, enzymes, or catalysts capable of self-regeneration).

A residual-protection indicator would eliminate the premature disposal of serviceable garments and might also be able to identify the type of contamination. Conductive polymers could be used with fiber-optic sensors to construct the device.

COLLECTIVE PROTECTION

Collective protective structures (e.g., shelters and positive pressure vehicles) provide relatively unencumbered safe environments where activities such as eating, recovery, command and control, and medical treatment can take place. Collective protective equipment is based on filtering and overpressurization technologies. Advanced filters and adsorbents are critical components in these systems. Improvements in protection will depend on the availability of advanced filtration and adsorbent capabilities.

Finding. The Department of Defense does not have enough collective protection units to meet the needs of deployed forces.

Recommendation. The Department of Defense should assess the needs of deployed forces for collective protection units in light of changing threats and the development of new personal protective equipment and provide adequate supplies of such equipment to deployed forces.

DECONTAMINATION

Decontamination is the process of neutralizing or removing chemical or biological agents from people, equipment, and the environment. For military purposes, decontamination must restore the combat effectiveness of equipment and personnel as rapidly as possible. Most current decontamination systems are labor intensive and resource intensive, require excessive amounts of water, are corrosive and/or toxic, and are not considered environmentally safe. Current R&D is focused on the development of decontamination systems to overcome these limitations and effectively decontaminate a broad spectrum of CB agents from all surfaces and materials. Because of the vastly different characteristics of personnel, personal equipment, interior equipment, exterior equipment, and large outdoor areas, situation-specific decontamination systems must be developed.

DoD has developed doctrine and training for decontamination but has not established levels of acceptable risk. Therefore, detection capabilities are not designed to verify acceptable decontamination levels.

Finding. Just as only a few benchmarks for the removal of MOPP gear have been established (because detection technology is inadequate), few benchmarks of decontamination levels have been established. Therefore, it is difficult to know when it is safe to return equipment to operational status and impossible to "certify" that previously contaminated equipment

can be transported to a new location, especially a location in the United States.

Recommendation. The Department of Defense should initiate a joint service, interagency, and international cooperative effort to establish decontamination standards. Standards should be based on the best science available and may require the development of new models for setting benchmarks, especially for highly toxic or pathogenic agents.

If residual decontamination levels are based on ultraconservative toxicity and morbidity estimates, returning contaminated equipment becomes impractical. Benchmarks for decontamination should be based on highly accurate, reliable, up-to-date toxicity data.

Finding. Although significant progress is being made with limited resources in exploring decontamination technologies that may be effective, no organized, integrated research program has been developed to meet the new challenges and objectives that have been posed (i.e., environmentally acceptable decontamination). Various agencies are actively pursuing many projects, but they are not well coordinated and do not have clear priorities for fixed-site programs, casualty management, and sensitive equipment programs.

Recommendation. The Department of Defense (DoD) should coordinate and prioritize the chemical/biological research and development (R&D) defense program, focusing on the protection of deployed forces and the development of environmentally acceptable decontamination methods. DoD should also establish the relative R&D priority of decontamination in the chemical/biological defense program.

Finding. Recent developments in catalytic/oxidative decontamination (enzymes, gels, foams, and nanoparticles) appear promising for decontaminating a wide range of CB agents.

Recommendation. Research on enzyme systems for battlefield decontamination (especially for small forces) should be given high priority because they could be used to decontaminate both personnel and equipment and would not require large volumes of water or complicated equipment.

Recommendation. The Department of Defense should continue to develop other catalytic/oxidative systems for larger scale decontamination. If possible, these systems should be less corrosive and more environmentally acceptable than current methods.

Finding. Low-power plasma technology has been shown to be effective for decontaminating sensitive equipment and has the potential of incorporating contaminant-sensing capabilities.

Recommendation. The Department of Defense should continue to develop plasma technology and other radiation methods for decontaminating equipment.

TESTING AND EVALUATION

Testing and evaluation of equipment, methodologies, and the toxicological effects of chemical agents are critical for the development of appropriate defensive strategies. Adherence to the principles of the nonproliferation agreements entered into by the United States prohibits most tests using live agents, as well as studies with human volunteers (except with surrogate agents). Most human and animal tests are, therefore, conducted using simulants, although it is not entirely clear that these simulants are adequate surrogates.

The most comprehensive test program, the Man-in-Simulant Test (MIST) Program, which tests complete and partial protective ensembles under controlled conditions, is a valuable program, although it has many shortcomings. Simulants are commonly used for testing protective and decontaminating equipment to determine the effectiveness of the protective equipment. However, the simulants have not been systematically validated to determine how closely their behavior mimics the behavior of actual agents. Therefore, the United States may not have the ability to determine whether or not a specific piece of equipment actually meets its performance requirements.

Finding. Testing of dermatological threat agents has not been consistent. The available quantitative data are not sufficiently precise to make an accurate evaluation of potential percutaneous threats from agents other than blister agents or irritants.

Recommendation. Tests of dermatological threat agents should be conducted to establish the level of protection necessary to provide adequate margins of safety and to establish quantitative criteria for evaluating the performance of protective equipment, such as gloves, undergarments, and overgarments.

Finding. Mask testing under the MIST program was unreliable because the passive dosimeters did not function satisfactorily in the mask environment.

Recommendation. Active samplers or improved passive samplers for mask testing using simulants should be developed and made available for tests of the joint service lightweight integrated suit technology (JSLIST) ensemble.

ASSESSMENT OF MILITARY CAPABILITIES TO PROVIDE EMERGENCY RESPONSE

Various initiatives have been implemented and numerous studies undertaken to determine the role and assess the capability of the U.S. military in providing emergency response capabilities in coordination with other federal, state, and local agencies. Examples of military programs to support emergency response include the DoD Chemical Biological Rapid Response Team, the U.S. Army Medical Research Institute of Chemical Defense Chemical Casualty Site Team, the Marine Corps Chemical Biological Incident Response Force, and the National Guard Rapid Assessment and Initial Detection Program.

Finding. Because numerous agencies will respond to a domestic CB incident, close coordination will be necessary for the response to be efficient and effective. Unless civilians (e.g., first responders, employees of relevant state and local agencies, etc.) who respond to domestic CB incidents are equipped with protective and decontamination equipment that is compatible with the equipment used by the military, coordination will be difficult if not impossible.

Recommendation. The Department of Defense, in collaboration with civilian agencies, should provide compatible equipment and training to civilians (e.g., first responders, employees of relevant state and local agencies, etc.) who respond to domestic chemical and/or biological incidents to ensure that their activities can be coordinated with the activities of military units. Doctrine and guidance must be developed on an interagency basis.

Finding. Doctrine and training are not well developed for mission-critical civilians working at military installations that might become targets of chemical and/or biological attacks.

Recommendation. Coordinated doctrine, training, and guidance on individual protective equipment, collective protective equipment, and decontamination should be established on a joint service, interagency, and coalition basis for civilians working at military installations.

SUMMARY AND GENERAL RECOMMENDATIONS

The health of military personnel who served in the Gulf War, and of personnel who will serve in future deployments, is a matter of great concern to veterans, the public, Congress, and DoD. Based on the many lessons that have been learned from the Gulf War and subsequent deployments, as well as on information from other sources, a great deal can be done to minimize potential adverse health effects from exposure to CB agents and to increase protection levels against them.

Recommendation. Threat projections and risk perceptions should be reevaluated in terms of realistic or credible battlefield risks. The requirements for protective equipment should then be adjusted to respond to those threats and challenges.

Characterizing a "low-level" contaminated environment is still an open question. Answering this question has become an urgent priority since post-Gulf War medically unexplained symptoms have become a serious issue. Information on the effects of extended exposures to low levels of CB agents is incomplete, but recent studies have suggested that low-level exposures may have some long-term consequences.

Recommendation. Research on the toxicology of low-level, long-term exposures to chemical and biological agents and other potentially harmful agents (e.g., environmental and occupational contaminants and toxic industrial chemicals) should be continued and expanded.

Unfortunately, modeling and simulation can only partly compensate for the lack of data based on actual experiments. Evidence has shown that modeling and simulation of the performance of CB protective equipment have not been very effective.

Recommendation. The use of simulants, data from animal models, and data on human exposure should be reevaluated as part of the development of a coherent research program to determine the physiological effects of both high-level and low-level long-term exposures to chemical and biological agents. The data should then be used to determine risks and challenges.

Training for CB operations has been very inconsistent, both within and among the services.

Recommendation. Required levels of training (with the appropriate level of funding for training devices and simultants) should be established and monitored for effective unit performance throughout the services. Objective criteria should be established for determining whether current service-specific training requirements are being met.

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Preface

Chemical and biological (CB) warfare has been the subject of numerous studies supported by a wide spectrum of sponsoring groups, ranging from the military to private sector foundations. Given how much has already been said on the subject, one might conclude that little remains on which to comment. However, the subject is complex and controversial enough that with each new hostile military encounter, with each potential new threat, with each report of a possible terrorist action using CB agents, our defensive preparedness comes under new scrutiny.

The military experience in the Gulf War, while overwhelmingly positive by almost any measure, raised some concerns. One obvious uncertainty was that there might be a causal relationship between the presence of CB agents in theater and the symptoms reported by returning military personnel, later named the "Gulf War Syndrome." Studies focused initially on whether personnel might have been exposed to low-level doses of chemical agents, and if this exposure could have resulted in the reported symptoms. More recent studies have been expanded to cover the whole range of CB defense, from medical issues to materiel development to doctrine and training.

Responding to the need for an evaluation of the military's ability to prosecute missions in CB environments, the Department of Defense Office of the Special Assistant for Gulf War Illnesses, through the National Academies, sponsored a study of strategies to protect the health of deployed U.S. forces, focused on CB defense. The first part of this three-year study was divided into four parallel studies (1) to develop an analytical framework for assessing the risks to deployed forces; (2) to review and

evaluate technologies and methods for detection and tracking exposures to those risks; (3) to review and evaluate physical protection and decontamination; and (4) to review and evaluate medical protection, health consequences and treatment, and medical record keeping. Now, at the end of the second year of the study, each group is providing a report to DoD and the public on its findings and recommendations in these areas. These four documents will be used as a basis for a new National Academies consensus committee that will prepare a synthesis report for DoD in the third year of the project. The consensus committee will consider, not only the topics covered in the four two-year studies, but also overarching issues relevant to its broader charge.

This report responds to the third of the first four studies, physical protection and decontamination. The task, which is more fully described in the first chapter, includes (1) an assessment of DoD's approaches and technologies for physical protection—both individual and collective—against CB warfare agents and decontamination of personnel and equipment, and (2) an assessment of DoD's current policies, doctrine, and training. The issues of space, budget, and staffing allocations for these programs, although extremely important, are beyond the scope of this report. Unlike most National Academies studies, two principal investigators conducted this study, with the assistance and guidance of an advisory panel. The expertise of this advisory panel covered various topics addressed by the study.

During the data-gathering phase, we received extensive briefings, visited various facilities, consulted with numerous experts, solicited commissioned papers on specialized topics, attended many related national conferences and symposia, and reviewed other material provided by DoD and from the open literature. We also held one workshop to gather additional information on focussed topics. We are indebted to the organizations and individuals that gave freely of their time and talents to this project. A special note of thanks to the individuals, listed by name, appears in Appendix F of this report. Given the countless individuals who shared their expertise with us, there is no doubt the list is incomplete; and we apologize for the oversights.

In responding to our Statement of Task, we attempted to cover each aspect of the requested information, adding introductory and historical information. No single study, however, can do justice to the entire breadth of topics included in our study charge. Therefore, we decided to focus on issues on which we believed we could provide especially helpful advice to the military.

During the course of the study, we were struck by several aspects of the CB defense community: (1) their dedication to their professions, in general, and to CB protection, in particular; (2) the extent to which

decades-old threat information continues to influence current requirements and considerations; (3) the willingness of policy makers to accept "worst case" assessments against which to develop programs, as opposed to developing more valid benchmarks based on more up-to-date information; (4) the continuing need for basic science information on the chemical, physical, and toxicological properties of CB agents to facilitate the development of modeling and simulations; (5) the need for more and better uses of modeling and simulations; and (6) the contrast between the high quality doctrine and training approaches available and inconsistent CB training across services and across units.

We wish to emphasize that the CB defense community is competent, caring, and dedicated. Although we suggest areas for improvement in this report, we retain a strongly positive overall impression of the work of the CB community.

The individuals who reviewed the draft report were especially important to the construction of the final report. They provided thoughtful and constructive comments that significantly enhanced the quality of the final report. Finally, we gratefully acknowledge the work and support of Beverly Huey, the National Academies study director for this project. Her dedication, intelligence, and flexibility were invaluable and are deeply appreciated. We also thank Laura Duffy, the research associate, for her efforts in acquiring and organizing data that were central to our analyses.

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Strategies to Protect the Health of Deployed U.S. Forces:
Physical Protection and Decontamination

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This report has also been reviewed by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the authors and the National Research Council in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The content of the review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in the review of this report:

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Abbreviations and Acronyms

ABBREVIATIONS

2D	two dimensional
3D	three dimensional
cfm	cubic foot per minute
CG	phosgene
Cl	chlorine
CK	cyanogen chloride
Ct	concentration × time
CX	phosgene oxime
D_{10}	the dose level required to reduce the sample population by a factor of 10
DS2	decontaminating solution number 2
DS2P	propylene glycol monomethyl ether
ECt_{50}	the *Ct* dose that causes a defined effect (e.g., edema or death) in 50 percent of a given population
GA	tabun
GB	sarin
GD	soman
g/den	gram per denier

H	Levinstein mustard
H2S	hydrogen sulfide
HD	distilled mustard
HL	mustard-lewisite mixture
HN	nitrogen mustard
ICt_{50}	the *Ct* dose that incapacitates 50 percent of a given population
ID_{50}	the dose that incapacitates 50 percent of a given population
L	Lewisite
lpm	liters per minute
MeV	million electron volts
m^2/g	square meter per gram
$mg \times min/m^3$	milligram times minute per cubed meter
mm	millimeter
nm	nanometers
NO_x	nitrogen oxides
ppb	parts per billion
Ω-kg/m^2	ohm kilogram per square meter

ACRONYMS

AERP	aircrew eye/respiratory protection
ALERT	attack and launch early reporting to theater
ASTM	American Society for Testing and Materials
AUIB	aircrew uniform integrated battlefield
BDO	battle dress overgarment
BDU	battle dress uniform
BWC	Biological and Toxic Weapons Convention
CB	chemical and/or biological
CBIRF	Chemical Biological Incident Response Force
CINC	commander-in-chief
CONUS	continental United States
CPE	collective protection equipment
CPU	chemical protective undergarment

CWC	Chemical Weapons Convention
DARPA	Defense Advanced Research Projects Agency
DATSD (CP/CBD)	Deputy Assistant to the Secretary of Defense for Counter-proliferation and Chemical/Biological Defense
DEPMEDS	deployable medical system
DoD	U.S. Department of Defense
DMMP	dimethyl methylphosphate
DPD	dermatopharmacodynamic
DPK	dermatopharmacokinetic
ERDEC	Edgewood Research, Development, and Engineering Center (now known as the Chemical-Biological Center of Excellence of the Soldier and Biological Chemical Command)
FF	fit factor
FM	field manual
FOC	functional operational capability
FR	flame resistance
FY	fiscal year
ICBPG	improved chemical and biological protective glove
IOM	Institute of Medicine
JCS	Joint Chiefs of Staff
JPO-BD	Joint Program Office for Biological Defense
JSAPE	joint service aircrew protective ensemble
JSAM	joint service aircrew mask
JSGPM	joint service general purpose mask
JSIG	Joint Service Integration Group
JSLIST	joint service lightweight integrated suit technology
JSMG	Joint Service Materiel Group
LCBPG	lightweight chemical/biological protective garment
LRC	lesser regional conflicts
LSC	liquid scintillation counting
MAG	military air guideline
MCBAT	Medical Chemical-Biological Advisory Team
MIST	Man-in-Simulant Test (program)

MLRS	multiple launch rocket system
MNS	mission needs statement
MOPP	mission-oriented protective posture
MRC	major regional conflicts
MULO	multipurpose rain/snow/CB overboot
MURI	multidisciplinary university research initiative
NATO	North Atlantic Treaty Organization
NBC	nuclear, biological, chemical
NMR	nuclear magnetic resonance
OOTW	operations other than war
OPAA	organophosphorous acid anhydrolase
OPH	organophosphorous hydrolase
P3I	preplanned product improvement (program)
PF	protection factor
POM	program objective memorandum
PPE	personal protective equipment
PVC	polyvinyl chloride
R&D	research and development
RDA	research, development and acquisition
RDIC	resuscitation device individual chemical
RDT&E	research, development, test and evaluation
RSDL	reactive skin decontaminant lotion
SAW	surface acoustic wave
SBCCOM	Soldier and Biological Chemical Command
SCALP	suit, contamination avoidance, liquid protection
SLS	sodium lauryl sulfate
SMART-CB	special medical augmentation response team–chemical/biological
SMART-PM	special medical augmentation response team–preventative medicine
SRT	Specialty Response Team
STEPO	self-contained toxic environment protective outfit
TAP	toxicological agent protective
TEMPER	tent, expandable modular personnel
TG	technical guide
VHP	vapor of hydrogen peroxide
VPU	vapor protective undergarment

Strategies to Protect the Health of Deployed U.S. Forces